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Properties of Dynamical Black Hole Entropy

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We study the first law for non-stationary perturbations of a stationary black hole whose event horizon is a Killing horizon, that relates the first-order change in the mass and angular momentum to the change in the entropy of an arbitrary horizon cross-section. Recently, Hollands, Wald and Zhang [1] have shown that the dynamical black hole entropy that satisfies this first law, for general relativity, is Sdyn=(1−v∂v)SBH, where v is the affine parameter of the null horizon generators and SBH is the Bekenstein-Hawking entropy, and for general diffeomorphism covariant theories of gravity Sdyn=(1−v∂v)SWall, where SWall is the Wall entropy. They obtained the first law by applying the Noether charge method to non-stationary perturbations and arbitrary cross-sections. In this formalism, the dynamical black hole entropy is defined as an "improved" Noether charge, which is unambiguous to first order in the perturbation. In the present article we provide a pedagogical derivation of the physical process version of the non-stationary first law for general relativity by integrating the linearised Raychaudhuri equation between two arbitrary horizon cross-sections. Moreover, we generalise the derivation of the first law in [1] to non-minimally coupled matter fields, using boost weight arguments rather than Killing field arguments, and we relax some of the gauge conditions on the perturbations by allowing for non-zero variations of the horizon Killing field and surface gravity. Finally, for f(Riemann) theories of gravity we show explicitly using Gaussian null coordinates that the improved Noether charge is Sdyn=(1−v∂v)SWall, which is a non-trivial check of [1].explicitly us- ing Gaussian null coordinates that the improved Noether charge is Sdyn = (1 − v∂v)SWall, which is a non-trivial check of [1].

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